Potential Economic Impacts of an Avocado Weevil Infestation in California

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1. Introduction

Purpose

The purpose of this report is to estimate economic impacts that would result from infestation of California's avocado groves by any of a set of exotic fruit and seed pests. *Copturus aguacatae*, a stem weevil which has been found repeatedly in intercepted avocados being smuggled from Mexico, and a seed weevil, *Conotrachelus aguacatae*, are representative of the pests of concern. U.S. avocado growers currently benefit from a comparatively pest-free environment, due in large part to inspection and quarantine regulations that have helped prevent such pests from entering the country. If entry were to occur, economic impacts would depend upon the cost and effectiveness of actions taken to control ensuing losses. In this study, potential impacts of infestation for U.S. avocado producers, consumers, and exporters are evaluated.

Approach

Consequences of infestation are examined for avocado producers and exporters, and at the broader social level of U.S. consumers and the avocado industry overall. The analysis is limited to expected effects, once infestation has taken place. Risk of pest entry and likelihood of colonization are not considered in the estimation of economic impacts.

The scenario developed for the analysis contains three basic assumptions:

- All areas of production in California would be infested, and eradication would not be possible.
- Growers would apply pesticides to minimize avocado losses, but yields would still be significantly reduced by the infestation.
- Pesticide application would affect natural, biological mechanisms that control indigenous pest populations, necessitating additional chemical treatments.

Direct impacts of infestation at the producer level are estimated in terms of (i) increased production costs due to pesticide treatments required to minimize fruit loss, and (ii) production losses that would result, despite the additional pesticide applications. U.S. avocado exporters could also be directly affected, if the infestation resulted in a loss of export markets. The likelihood of a contraction of exports as a result of phytosanitary restrictions imposed by importing countries is evaluated.

Social, or welfare, losses are estimated in order to examine the full dimensions of infestation for producers and consumers. Treatment costs and reduced yields would decrease the domestic supply of avocados, resulting in an increase in the market price. Buyers would likely reduce their avocado purchases in response to the price rise. A new price-quantity equilibrium would be determined, with associated losses in producer and consumer surpluses.

Using time-series data and econometric modelling of the supply and demand for avocado, these welfare losses are evaluated.

Outline of the Report

Section 2 provides background information used to develop the infestation scenario. Statistics and characteristics of avocado production in the United States, and in California in particular, are presented. Weevils representative of the set of exotic pests of concern, and existing problems faced by California avocado growers are identified.

Potential direct impacts of the infestation on U.S. avocado production and exports are described in Section 3. Scenario assumptions that underlie the estimation of financial consequences are explained. Expected changes in production costs, yields, and U.S. exports are discussed.

Section 4 examines the social losses of infestation that would be borne by U.S. avocado producers and consumers. The model used to analyze changes in economic welfare is presented graphically and algebraically. Price elasticities of supply and demand for avocado, used to determine expected losses of consumer and producer surplus, are estimated. The sensitivity of the analytical results to variations in the assumed cost increase, yield decrease, and elasticities is examined.

2. U.S. Avocado Production and Pests of Concern

U.S. Avocado Production[1]

Overview. The United States is second only to Mexico in avocado production, averaging 215,000 tons per year since 1980.[2] About 85 percent of U.S. production takes place in coastal southern California, and the remainder in southern Florida. (Hawaii also produces a small quantity, which in 1990/91 totaled 450 tons.)

Avocados are produced year-round, with storage on the tree possible for several months. However, variation in yearly production, as shown in Figure 1, can be considerable. U.S. production totaled 302,700 tons in 1986/87, whereas in 1990/91 only 145,050 tons were produced (USDA 1991). Yields fluctuate because of weather conditions and the avocado tree's tendency to bear more heavily in alternate years. The 1990/91 shortfall, for example, can be attributed to extremely high temperatures in California during the fruit set period and a freeze in Florida in December 1989.

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[1]Much of the background information presented on avocado production has been drawn from the American Farm Bureau Research Foundation (1991).

[2]Tons used in this study are short tons, or 2000 pounds.

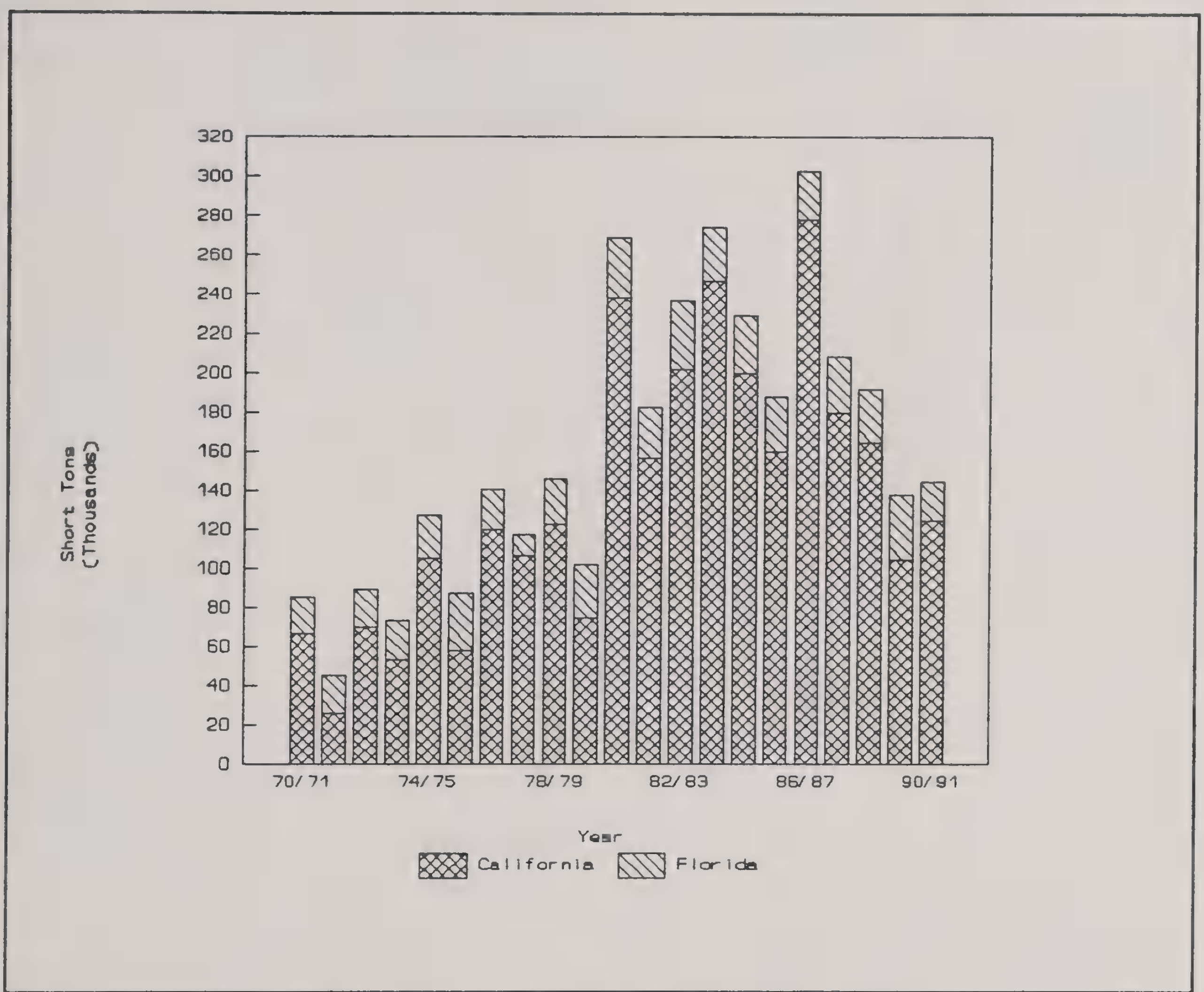

Figure 1 U.S. Avocado Production, 1970/71-1990/91
Source: USDA (1991).

California and Florida produce distinct varieties of avocado. Over 85 percent of California's acreage is planted in the widely preferred and higher-yielding Hass variety, while Florida's higher humidity limits production options to lesser-valued "green-skinned" varieties. The price premium enjoyed by growers of the dark-skinned Hass can be substantial. In 1987/88, for example, Hass producers in California received $1,140 per ton, while Florida varieties brought only $312 per ton.

About 95 percent of avocados produced in the United States are consumed domestically, with only about 10,000 tons exported annually between 1987 and 1990. As production of export-quality avocado expands in Mexico and elsewhere, U.S. producers can expect to face continued competition in maintaining their share of foreign markets. In 1989, avocados from

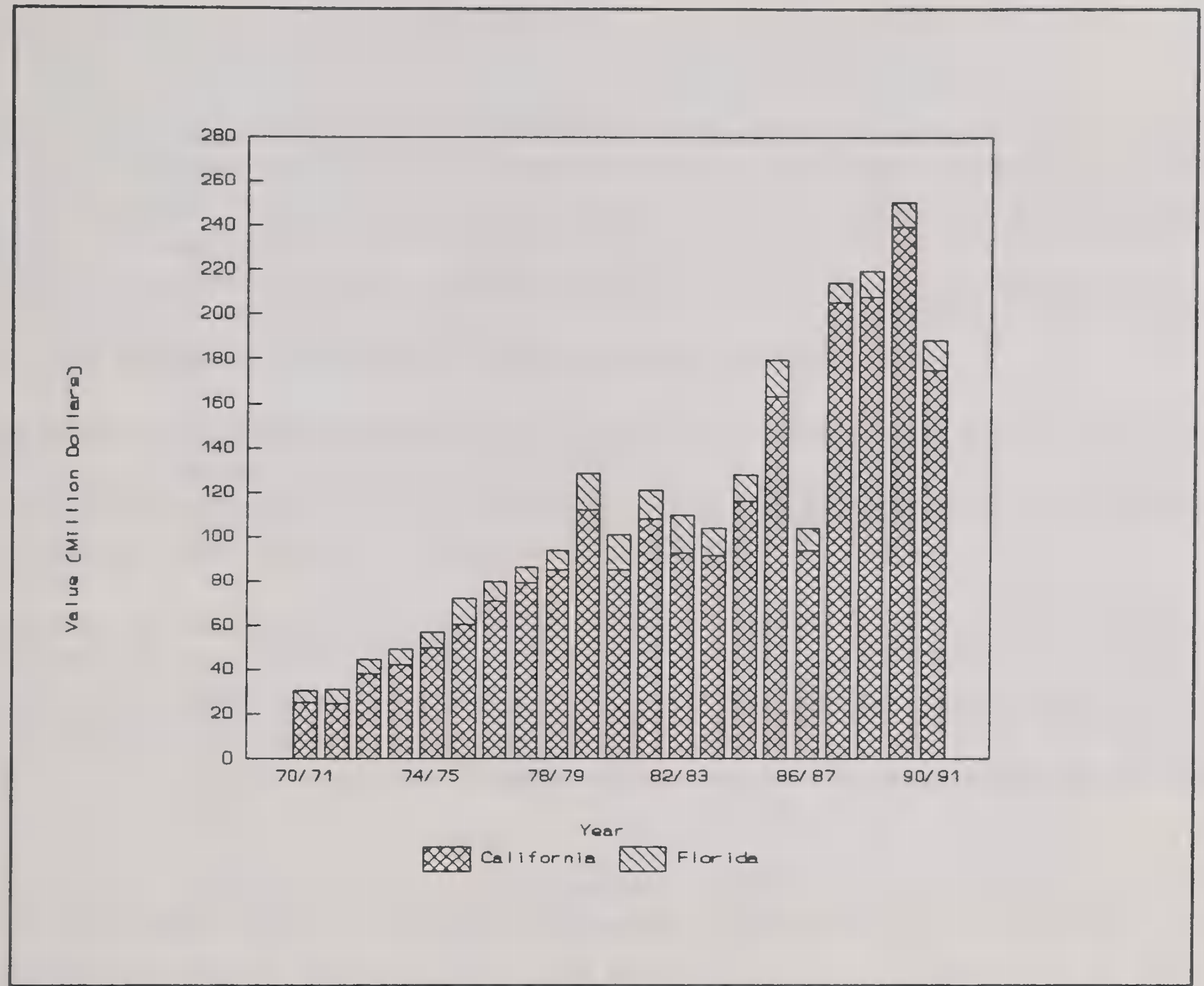

Figure 2 Value of U.S. Avocado Production, 1970/71-1990/91
Source: USDA (1991).

Mexico, Spain, and Israel were supplying the French market at prices well below California prices before shipment (*California Grower* 1989).

Avocados imported into the United States come mainly from Chile and the Dominican Republic (87 percent and 12 percent, respectively, of 1990 imports), and mainly serve U.S. markets during California's off-season. The total quantity imported has grown significantly in recent years, reaching 10 percent of fresh domestic production in 1990, compared to between 1 and 2 percent during the late 1970s and early 1980s (Brown and Suarez 1991; USDA 1991, 1992). Thus, the United States is a net importer of avocados, but neither the amounts imported or exported are major.

California Production. California avocado producers number about 6,300. Nine percent of these farmers have groves of 25 or more acres, and own two-thirds of the state's total acreage. Annual value of production since 1980 has averaged $143.5 million, and reached $239.4 million in 1989/90 (Figure 2). Production standards are set by the California

Department of Food and Agriculture, based on recommendations received from the California Avocado Commission (CAC), a grower funded organization.

The avocado tree's sensitivity to cold weather delimits California's growing area: 98 percent of the state's groves are located along the southern coast. San Diego County alone accounts for approximately one-half of the state's total acreage, with the balance found in Riverside County and coastal counties to the north. Yields are much the same throughout the state, although, as mentioned above, production varies from year to year. The highest average yield during the 1980s was 4 tons per acre in 1980/81, whereas in 1989/90 only 1.4 tons per acre were obtained (American Farm Bureau Research Foundation 1991).

Peak shipping by California producers takes place during the late spring and early summer, with most production marketed in the months of March through July. Only one-fourth of the year's harvest is marketed from October through February. Minor varieties are marketed in the winter and early spring, when supplies of Hass are at their lowest.

Concerted marketing efforts have been instrumental in broadening consumer demand and maintaining production levels during the past decade, despite yield fluctuations and reduced acreages. The state's total area in avocados has fallen by 15 percent since the late 1970s, to about 68,000 acres, and is expected to stabilize at about 60,000 acres (*California Grower* 1990).[3] Less than 0.5 percent of California acreage was non-bearing in 1989, compared to more than 24 percent in 1970.

Urbanization and rising production costs underlie this decline in acreage. Increasing land prices in southern California have meant comparatively low profitability for avocado production; as was aptly stated, "...San Diego growers are in two businesses and the first is real estate" (*California Grower* 1987). A 1987 survey found that land planted in avocado groves could be sold for $30,000 per acre when its agricultural value was only $6,000 per acre (Bekey 1988).

In addition to urban encroachment, rising irrigation costs and other production expenses are expected to limit avocado acreages over the long run. Mounting water expenses, which have reached as high as $400 per acre-foot in San Diego County, are representative of increasing costs of production faced by growers.

In response to rising land values and production costs, growers are turning to more intensive management of their higher-yielding groves. Much of the land that has been taken out of production has been low-yielding. By concentrating resources on the care and maintenance of their more productive groves, producers have been able to increase yields and maintain production levels.

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[3]Between 1987 and 1990, land devoted to avocado production decreased by 11 percent in Riverside County and 17 percent in San Diego County (Chess 1990).

Florida Production. The Florida avocado industry is much smaller than California's, with producers numbering 440 in 1988/89 (*Florida Avocados* 1991). Sales averaged $13 million per year during the 1980s, and have never accounted for more than 15 percent of U.S. production (Figures 1 and 2).

Production is year-round as in California, but peak production is in September rather than in the spring. Yields are also less variable, ranging from 2.2 to 3.5 tons per acre. Whereas California growers market their avocados according to state standards, a federal marketing order provides production standards for Florida producers, as well as support for research and promotional activities.

As in California, urbanization during the late 1980s contributed to a state-wide decline in land planted in avocado. From 1984 until the recent devastation wreaked by Hurricane Andrew, Florida's avocado acreage decreased by more than one-fourth, from 12,872 to 9,078 acres (99 percent of the trees bearing). Dade County, which contained 99 percent of Florida's avocado groves before the hurricane struck, experienced an 11 percent decrease in acreage between 1988 (10,076 acres) and 1990 (8,987 acres) (*Florida Avocados* 1991). Like their counterparts in California, Florida's producers will be depending on improved yields to maintain annual production levels, once the groves destroyed by Hurricane Andrew are replanted.

Avocado Pests of Concern

Characteristics of *Copturus aguacatae* and *Conotrachelus aguacatae*, two weevils representative of the avocado pests with which this study is concerned, are briefly described below.[4] Existing pest problems faced by California avocado producers are then reviewed.

Two Exotic Pests. *Copturus aguacatae*, found in Mexico, is a pest only of the avocado. It bores into small, new stems or branches, and eggs are oviposited in the epidermis of the plant. Boring causes die-back of the branches and possible reduction in tree size and yield. This stem weevil is considered a major avocado pest; in addition to the destruction caused directly, it fosters secondary infections by bacteria, fungi, and viruses. It can be controlled with repeated foliage spraying of contact pesticides.

Conotrachelus aguacatae, reported in Mexico and Central America, also has the avocado as its sole host. Eggs are oviposited on young fruit and the larvae migrate to the seed, where they feed until the avocado matures. When the fruit is fully developed, the larvae exit the fruit and pupate in the soil. Adults of this seed weevil are active at night and feed to some degree on the fruit, leaves, and stems of avocado trees. It is ranked as a minor avocado

[4] Descriptions of the exotic pests of concern are presented in Appendix 1. Besides *Copturus aguacatae* and *Conotrachelus aguacatae*, they include the seed weevils, *Conotrachelus perseae* and *Heilipus lauri*, and the seed moth, *Stenoma catenifer*.

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pest, and field control in Mexico includes foliage and ground application of pesticides, raking of the ground to expose pupae, and collection and destruction of fallen fruit.

Existing Pest Problems in California. In comparison to other crops grown in California, avocados have relatively few pests. Routine application of pesticides is not necessary, other than for the control of occasional outbreaks of insects and mites. Described here are four insect species and two mite species considered to be principal avocado pests in California. (The information has been compiled from Bailey and Olsen 1990a, Bailey and Olsen 1990b, Bekey 1990, McMurtry 1989, and Oatman and Platner 1985.)

The Amorbia moth (*Amorbia cuneana*) feeds on the foliage and fruit surface of avocados. Natural enemies generally prevent this insect from causing major damage. Periodic increases in population are kept in check by biological means, including the timed release of parasitic wasps and the use of the bacterium, *Bacillus thuringiensis*. Lannate® (methomyl) is a broad-spectrum insecticide used for spot treatment, but it also kills beneficial predators and parasites.

An omnivorous looper, *Sabulodes aegrotata*, is found in most groves, but does not cause significant damage. When necessary, populations are controlled by the same means as are used for the Amorbia moth.

Greenhouse thrips (*Heliothrips haemorrhoidalis*) feed on the avocado fruit, and the resulting scarring reduces the market value of the fruit. The pest is found in most groves, but groves are treated with malathion only on occasion when the pest populations mount.

Hemibelesia lataniae, an armored scale insect, was once considered the most serious pest of avocados in California. Apparently, natural enemies now keep this pest under control.

The avocado brown mite, *Oligonyshus punicae*, feeds on avocado leaves and large populations can cause significant leaf drop. It is generally controlled by natural predators and parasites, including a *Stethorus* beetle and predaceous mites. Flowable sulfur and spray oil can be used, although neither pesticide is considered entirely effective.

The six-spotted spider mite, *Eotetranychus sexmaculatus*, can also cause leaf drop. Natural and applied controls are the same as for brown mite. Outbreaks can result indirectly from spraying for other pests, such as the application of malathion for thrips.

In summary, control complexes involving natural predators and parasites operate to keep the insect and mite pests of California avocados in check for most of the time. When pest populations do escalate, fruit damage can be significant. These occasions may require biological intervention, such as the release of known parasites of the pest, or chemical applications. Chemical treatment can result in secondary impacts harmful to the avocado crop, as exemplified by the depopulating of natural predators of mites by the application of malathion.

3. Infestation Assumptions and Expected Impacts for Producers and Exporters

The Infestation Scenario

Since infestation of California avocado groves by a pest such as *Copturus aguacatae* or *Conotrachelus aguacatae* (hereafter collectively referred to simply as the "weevil") is hypothetical, assumptions with respect to the pest's impacts and producers' responses are required. The weevil is proxy for a set of exotic avocado pests, described in Appendix 1, which are similar in terms of their host, the part of the host they attack, crop damage they can cause, and methods by which they can be controlled. Nevertheless, the pests are distinct species. Broadly stated assumptions regarding crop damage and producers' responses, therefore, are appropriate, given the range of pests represented.

Extent of Weevil Infestation. A basic assumption of the analysis is that the weevil would colonize and thrive in California. It is not known whether California's climatic and other environmental conditions—particularly winter temperatures—would enable any of these pests to become established, even if introduced. In Mexico, their distribution is limited by factors other than host availability; whereas the seed moth, *Stenoma catenifer*, seems to be restricted to the more tropical regions along Mexico's coastlines, the stem and seed weevils tend to be found in the highlands. None of the pests of concern is found throughout Mexico's avocado growing areas. Similar climatic limitations might well occur in California, if colonization were to take place. However, rather than attempt to incorporate estimations of climatic limitations in this study, it is assumed that California's groves would experience universal infestation, although not all trees would necessarily be affected. In this sense, the impacts calculated are more severe than would be the case if the area of infestation were limited by climatic or other factors.

Control of the Weevil. A second set of assumptions concerns options for controlling the infestation. Financial and regulatory circumstances for California's avocado producers differ from those of their Mexican counterparts. Interrupting the life cycle of *Conotrachelus aguacatae* by raking and picking up fruit from beneath avocado trees is a major means of controlling this weevil in Mexico. California labor costs, not to mention the hilly, rocky land on which many groves are planted, make physical control alternatives cost-prohibitive.[5] Consequently, it is reasonable to assume that California producers would depend upon

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[5]Labor costs in Mexico in 1987 represented 30 to 40 percent of total production costs, whereas in California they comprised over 50 percent (American Farm Bureau Research Foundation 1991). The agricultural wage for fruit and nut crops in the South Coast area of California in May 1992, was $6.47 per hour, according to the California Employment Development Department (Mr. Avi Crane, CAC, personal communication). Regarding the terrain of California's groves, it is estimated that 75 to 85 percent of the avocado groves in San Diego County, 70 percent in Riverside County, and 50 to 60 percent in Santa Barbara and Ventura Counties, are located on hillsides with slopes of 15 degrees or more (Mr. Avi Crane).

chemical applications, at least until there was time to develop preferred biological control methods.

The chemicals used would need to satisfy California's regulatory restrictions for the use of pesticides. According to the Federal Insecticide, Fungicide, and Rodenticide Act, as amended, growers can use a pesticide to control a pest other than the one for which it is labeled, as long as it is for the same crop; the same or lower dosage, concentration, and frequency; and if other application requirements are met. Currently, there are several formulations of two insecticides, malathion and Lannate® (methomyl), that are registered for use in California for avocados. Malathion is registered for the control of greenhouse thrips and Lannate® is registered for the control of the Amorbia moth and the omnivorous looper. Both pesticides are broad spectrum and are applied to foliage.

Given the cost and time required for testing and registering insecticides, it can be assumed that foliage application of either malathion or Lannate® would be relied upon for controlling weevil populations, at least for several years following the outbreak.[6] Eventually, methods of control more desirable than these broad-spectrum pesticides likely would be developed, such as more selective insecticides. Perhaps a pheromone would be produced, to be used as a monitoring tool for timing the release of a biocontrol agent or chemical spray. However, for the near-term responses hypothesized in this scenario, growers are assumed to use a formulation of malathion currently registered for other pests and in use in California groves, such as Prokil 8E®.

The number of times per year that the insecticide would be applied is difficult to estimate, as it would depend on the population levels of the pest in the growing areas, the period of time during which the weevil can lay eggs in the stem or fruit, and the effectiveness of the pesticide. To control insects similar to the weevil, malathion is applied once a week during the time adults are present and oviposition is taking place. Studies conducted in Mexico suggest that the infesting weevil would propagate through two generations per year.[7] To control the infestation, this study assumes that the growers would apply malathion from 12 to 16 times per year, or 14 times on average. Despite treatment with malathion, it is assumed that damage caused directly by the weevil would reduce average avocado yields by 10 percent.

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[6]Of the two insecticides, Lannate® is known for its effectiveness in controlling lepidopterous pests (Bailey and Olsen 1990a), although it is registered for certain beetles having other crop hosts. These include the bean leaf beetle, the Mexican bean beetle, and the spotted cucumber beetle. Malathion is registered and known to be effective against a number of weevils that infest crops other than avocado. Some of these weevils are closely related to the targeted pests and have similar biology, such as the plum curculio (*Conotrachelus nenuphar*), the boll weevil (*Anthonomus grandis*), and the strawberry bud weevil (*A. signatus*).

[7]For *Copturus aguacatae*, Muniz (1959) found that oviposition occurred over a two-month period in the spring and over another two-month period in the fall. Dr. Sleeper, Long Beach State, captured adult *Conotrachelus aguacatae* in blacklight traps for periods of at least three months in the same location in Mexico, suggesting that adult females were able to lay eggs for a large portion of that time (personal communication).

<u>Indigenous Pest Outbreaks</u>. As stated above, California avocado producers experience relatively few pest problems and routine application of pesticides is not practiced. The Amorbia moth, omnivorous looper, avocado brown mite, six-spotted spider mite, and other pests are generally kept under control by predators and parasites.

Mite problems experienced by producers usually arise when pesticides are used to control other infestations. The use of malathion to control greenhouse thrips, for example, can result in eruptions of six-spotted spider mite populations. McMurtry (1985) notes that if spray application for other pests is necessary to avoid serious crop losses, annual infestations of mites can be anticipated.

Given the high probability of mite outbreaks as a result of universal treatment by malathion, and possible problems with the Amorbia moth, the omnivorous looper, and the latania scale as well, it is assumed that avocado producers would sustain an additional 10 percent crop loss from these secondary infestations. This decline in yield would occur even though it is assumed that growers would apply chemical controls in the form of Omite® and Lannate® each three times a year. A special exemption of California's pesticide regulations was required for the application of Omite® to combat a widespread mite outbreak this year. Similar exemptions would be required in this scenario.

<u>Methods of Pesticide Application</u>. Pesticide treatment costs for California avocado growers generally would favor aerial application, due to the large scale at which most production takes place, the steep slope of much of the land, and the cost of labor. Nevertheless, over 90 percent of California's avocado producers have holdings of less than 25 acres. The groves of these relatively small-scale operations yield about one-third of the state's total production. Their small size (eight acres on average) and frequent proximity to populated areas would favor ground application of the pesticides.

A critical element in the choice of method would be producers' perceptions of the relative effectiveness of aerial and ground spraying. Because avocado trees can form a thick canopy, an insecticide applied by air would remain concentrated on the tops of leaves, especially at the upper side of the foliage. Weevils, mites, loopers, and other pests located in lower parts of the tree would be at least partially protected from the spray. This problem of inadequate spray coverage has been demonstrated in field tests using Lannate® and Orthene® to control the Amorbia moth. Both insecticides were effective when applied using ground equipment, but neither was effective when applied by helicopter. Aerial application of a miticide to combat a mite outbreak in 1992 also proved to be only partially effective.

Ultimately, each producer would decide upon the method of application best suited to his or her circumstances. In many instances, application by back-pack or tractor-drawn sprayers would not be practical, because of the terrain and the close spacing of trees. In other cases, nearby residential areas would preclude aerial application. To generalize producers' application decisions for the purposes of this study, it is assumed that two-thirds of the state's acreage would be aerially sprayed, and one-third would be treated using back-pack sprayers.

Hypothesized levels of crop loss caused by the weevil (10 percent of normal yield) and indigenous pests (an additional 10 percent), are assumed largely in recognition of the limited effectiveness of aerial treatment.

Interstate Quarantines. It is assumed that APHIS and/or state plant health agencies would act to prevent the spread of the infestation by prohibiting avocado fruit shipments from California to Florida and Hawaii.[8] For *Copturus aguacatae* and *Stenoma catenifer*, nursery stock would also be restricted.

U.S. Avocado Imports. The quantity of avocados imported into the United States compared to domestic production is not great, but has been increasing in recent years. It averaged about 1.3 percent of U.S. production over the period 1975 to 1987, and grew to 3.8 percent in 1988, 3.7 percent in 1989, and 10.2 percent in 1990 (Brown and Suarez 1991; USDA 1991, 1992). The price rise resulting from a weevil infestation of California's avocado groves would reinforce this trend. However, avocado imports would not increase significantly, since restrictions on the importation of avocados from Mexico, Central America, and most of South America would be maintained. Therefore, it is assumed that the U.S. avocado supply would not be notably affected by additional imports.

Summary of Assumptions. Assumed pesticide treatments and fruit losses provide a basis for estimating near-term economic impacts of a weevil infestation. As mentioned above, it is likely that in the long run more effective chemical or biological control methods would be developed.[9] It is also likely that producers would reduce losses by modifying their cultural practices. For example, growers might lessen the fruit's exposure to infestation by curtailing the period during which ripe fruit is "stored" on the tree.[10] However, long-term improvements in pest control methods and cultural practices are not included in the scenario. A simplified set of impacts and responses are assumed:

- Infestation in California would occur in all avocado growing areas.
- Producers would apply malathion by air or by ground, 14 times a year to all avocado groves, in order to control the weevil infestation.

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[8]Similar restrictions have been applied for other newly introduced pests with restricted host range. As an example, interstate movement of regulated articles from the lower Rio Grande Valley in Texas to citrus-producing areas is restricted because of the Mexican Fruit Fly infestation.

[9]The control of the Amorbia moth using the timed release of parasitic wasps and the bacterium, *Bacillus thuringiensis*, is an example of avocado growers' current reliance upon biological control methods.

[10]However, as pointed out by Isi A. Siddiqui, California Department of Food and Agriculture, storing of avocados on the tree provides a certain price stability that would be otherwise lost (personal communication).

- Producers would apply Omite® and Lannate® by air or by ground, three times a year to all avocado groves, in order to control outbreaks of mites, loopers, and other indigenous insects that would likely occur following the malathion treatments.

- Despite malathion treatments, the weevil infestation would cause a direct crop loss of 10 percent.

- Despite Omite® and Lannate® treatments, indigenous pest outbreaks would cause an additional 10 percent crop loss.

- Shipments of avocado fruit from California to Florida or Hawaii would be restricted.

- Avocado imports due to the price rise would not significantly increase, and therefore would not change the quantity available for U.S. consumption.

Expected Effects of Infestation for Producers

Increased Input Costs. The cost of controlling a weevil infestation of California groves would depend upon the cost of the pesticides described above and their application. The most recent published survey of avocado production expenses in California was performed in 1987 (Bekey 1987, 1988). Annual production costs, including cultural operations, overhead, harvesting, and capital depreciation and interest, was estimated by Bekey to total about $5,650 per acre per year. Although the costs of a number of inputs have risen since 1987, the avocado industry views Bekey's estimation as representative of current average yearly expenses.[11]

Table 1 shows the additional costs that would be borne by avocado producers due to weevil infestation. As indicated, additional pesticide applications are estimated to increase growers' annual costs of production by a composite 41 percent.[12] The cost of malathion and its application per acre would constitute two-thirds of all additional pesticide costs. The cost of the Omite® treatment may be slightly overestimated, depending upon whether all avocado acreage would be allowed to be sprayed. The special exemption that permitted the use of Omite® this year required that a portion of the groves not be treated, in order that natural biological controls not be completely disrupted.

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[11]Mr. Avi Crane, CAC, personal communication.

[12]This percentage increase in costs in slightly overestimated. Because yields are assumed to decline by 20 percent, per acre costs associated with some cultural practices, particularly harvesting, would also decrease. Bekey (1987) indicates picking and hauling costs as comprising about 12 percent of total costs, so that a 20 percent yield decrease would roughly compare to less than a 3 percent savings in production costs. This relatively small change in production costs is not included in the calculations.

Table 1

Estimated Increase in Production Costs per Acre, as a Result of Pesticide Applications to Control the Weevil Infestation and Other Pest Outbreaks[1]

Pesticide	Cost	Quantity per Application (per acre)	Cost per Application	Applications per Year	Cost per Year
Prokil 8E® (malathion)	$32/gallon	1 gallon	$32.00	14	$448.00
Lannate L®	$35/gallon	1/4 gallon	$8.75	3	$26.25
Omite®	$5.50/pound	15 pounds	$82.50	3	$247.50

Total Additional Pesticide Costs:	$721.75
Application costs by helicopter, for two-thirds of infested groves (20 applications @ $40 per application per acre x ⅔):[2]	$533.33
Application costs by back-pack sprayer, for one-third of infested groves (20 applications @ $160 per application per acre x ⅓):[3]	$1,066.67
Total Additional Pesticide and Application Costs:	$2,321.75
Estimated Production Costs Without Infestation:	$5,650.00
Percentage Increase in Production Costs With Infestation:	41%

[1]The cost of water for dilution of the pesticides is not included.
[2]Separate applications are assumed for each pesticide treatment, when in fact some might be combined to reduce costs.
[3]Estimated cost assumes approximately three person-days required to spray one acre, at a labor cost of about $6.50 per hour.

Decreased Yields. Due to the limited effectiveness of the aerial applications, pest populations would still reach damaging levels. Yields would decline overall by an assumed 20 percent. It is unlikely that the processed avocado market would provide an outlet of significant scope for the damaged fruit, since relatively high-quality avocados are required.[13] Thus, growers would see their production costs increase on average by about

[13]Mr. Avi Crane, CAC, personal communication.

two-fifths, while their yields decreased by one-fifth. The ability of producers to absorb concomitant input and output shocks of this magnitude would depend upon each one's circumstances. Operations for which revenues barely cover costs could fail. More profitable operations would have diminished returns, if not short-term losses. The avocado industry as a whole would suffer a welfare loss, which is the subject of Section 4.

Interstate Shipments. It is assumed that movement of avocado from California to Florida and Hawaii would be prohibited because of the weevil infestation. The quantity of California avocados shipped to Florida in 1991/92 was about 1,745 tons. During this same period, only about 13 tons of California avocados were shipped to Hawaii. These amounts represent very small shares of California's production (about 1.1 percent in the case of Florida).[14] Nevertheless, excess demand for avocados following infestation would encourage an expansion of Florida's production, in particular, notwithstanding the differences in varieties.

Expected Effects of Infestation on U.S. Exports

About 5 percent of U.S. avocado production is exported. The principal markets are Japan (27 percent of annual U.S. exports between 1987 and 1990), France (23 percent), the United Kingdom (13 percent), the Netherlands (6 percent), and Sweden (5 percent).[15] None of these nations produces avocados. Moreover, Mexico, which harbors all of the pests of concern, exports avocados to these same countries. Therefore, it is not likely that U.S. avocado exports would be significantly affected by phytosanitary restrictions.

However, the weevil infestation would result in increased prices for California avocados, making U.S. avocado exporters less competitive in world markets. Even without the imposition of phytosanitary restrictions by other countries, U.S. exporters would suffer market losses. In addition, the development of new export markets in avocado-growing regions of the world would be hampered, if phytosanitary safeguards prohibited the entry of U.S. avocado exports or required special inspection or treatment.

4. Social Losses for U.S. Avocado Producers and Consumers

The Analytic Model

Impacts for society of an avocado weevil infestation in California derive from the increased costs and reduced yields described in Section 3. The resulting welfare losses can be estimated in terms of changes in consumer and producer surplus (see Appendix 2).

The analysis of social losses is introduced by depicting graphically the impacts for producers and consumers. Using time-series data to estimate avocado supply and demand functions,

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[14]Mr. Avi Crane, CAC, personal communication.

[15]See Appendix II of Grimes (1992).

[illegible] what prices [illegible] in [illegible] in [illegible] and [illegible] on [illegible] and [illegible] [illegible] [illegible] [illegible] [illegible] of [illegible].

[illegible] California [illegible] of California's [illegible] [illegible] [illegible] [illegible] including the [illegible]

[illegible] of U.S. [illegible] [illegible] [illegible] U.S. [illegible] [illegible] [illegible], the [illegible] of [illegible] [illegible] [illegible] would be significant [illegible]

[illegible] in [illegible] for [illegible] [illegible] U.S. [illegible], the development [illegible] [illegible] [illegible] [illegible] [illegible] or [illegible].

[illegible] for U.S. [illegible] Producers and Consumers

losses are then evaluated for the assumed rise in cost and reduction in yield. The sensitivity of the results to different assumptions concerning cost increases, yield decreases, and producer and consumer responsiveness to avocado price changes (price elasticities of supply and demand) is then examined.

Graphical Analysis

Welfare effects of increased marginal costs of production for a competitive industry can be diagrammed as shown in Figure 3. Supply and demand for avocados, without a weevil infestation, are represented by the curves labeled S_1 and D. The market clears at point *c*, where the quantity demanded equals the quantity supplied. The equilibrium quantity is Q_1 and the equilibrium price is P_1.

The two impacts on avocado production described in the scenario, the increase in production costs and the reduction in yields, are indicated as separate upward shifts of the supply curve, to S_2 and S_3, although in reality they would be occurring simultaneously. The shift represented by r_1 corresponds to the increase in production costs. The reduction in yield, which corresponds to a leftward shift of the supply curve, can be interpreted for the purposes of our model as a second upward shift, r_2. Welfare losses, therefore, derive from the combined effects of r_1 and r_2.

Consumer surplus without infestation corresponds to area acP_1 and producer surplus, to area P_1cg. With combined shifts in the supply curve of r_1 and r_2, quantity decreases from Q_1 to Q_3 and the price rises from P_1 to P_3. The new consumer surplus is represented by the area abP_3, while the new producer surplus is equal to area P_3bf. The decrease in consumer surplus (CL) is represented by area P_3bcP_1 and the decrease in producer surplus (PL) is represented by area P_1cde (area P_1cg less area P_3bf). The decrease in total surplus (TL) is the sum of the producer loss and consumer loss and is given by area P_3bcde (which is also equal to area *fbcg*). As can be seen from the figure, the areas representing consumer loss and producer loss are trapezoids. Changes in producer surplus, consumer surplus, and total surplus can be determined by estimating price elasticities of supply and demand and then calculating the areas of these trapezoids.

Algebraic Analysis

Equations for calculating the areas in Figure 3 that represent consumer loss (CL), producer loss (PL), and total loss (TL) are as follows:

$$CL = 0.5(P_1 - P_3)(Q_3 + Q_1) \qquad (1)$$

$$PL = 0.5\{(P_3 - P_1) - (r_1 + r_2)\}(Q_3 + Q_1) \qquad (2)$$

$$TL = CL + PL \qquad (3)$$

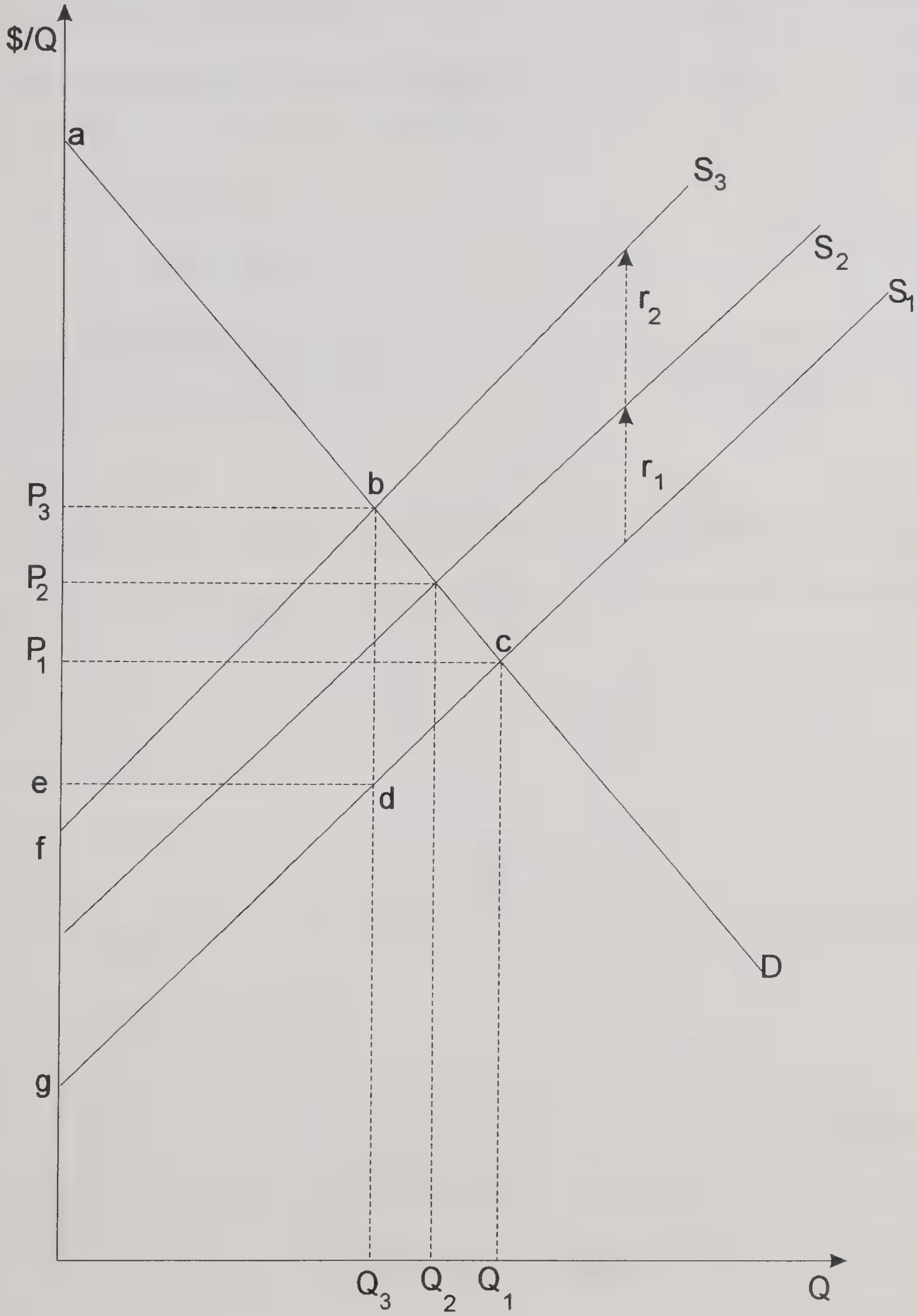

Figure 3. Welfare effects of upward shifts in the supply curve.

where, P_1 is the initial equilibrium price, Q_1 is the initial equilibrium quantity, P_3 is the new equilibrium price, Q_3 is the new equilibrium quantity, and r_1 is the per unit cost increase and r_2 is the yield decrease interpreted as an upward shift in the supply curve.

A new equilibrium quantity (Q^*) and equilibrium price (P^*) after an upward shift in the supply curve can be determined as follows:[16]

$$Q^* = Q\{1-(k\varepsilon\eta/(\varepsilon+\eta))\} \qquad (4)$$

$$P^* = P\{1+(k\varepsilon/(\varepsilon+\eta))\} \qquad (5)$$

where, k is the proportional upward shift in the supply curve ($k=r/P$), ε is the price elasticity of supply ($\varepsilon=\delta Q^S/\delta P(P/Q^S)$), and η is the absolute value of the price elasticity of demand ($\eta=|\delta Q^D/\delta P(P/Q^D)|$).

Calculation of Q_3 and P_3 of Figure 3 is performed in two stages. In the first stage, in which $Q^*=Q_2$, $Q=Q_1$, $P^*=P_2$, and $P=P_1$, k is defined in terms of r_1 and P_1, and ε and η have their initial values. The second stage ($Q^*=Q_3$, $Q=Q_2$, $P^*=P_3$, and $P=P_2$) defines k using r_2 and P_2, and ε and η have new values that correspond to P_2 and Q_2, the intersection of the demand curve, D, and the intermediate supply curve, S_2.

Substituting equations 4 and 5 into equations 1 and 2 yields:

$$CL = -.5PQz(2-z\eta) \qquad (6)$$

$$PL = .5PQ(z-k)(2-z\eta) \qquad (7)$$

where, $z=k\varepsilon/(\varepsilon+\eta)$ and the other terms are as defined above. The social loss and its distribution between producers and consumers can be quantified using equations 6 and 7.

Specification of Price Elasticities

Empirical estimation of the social loss requires specification of price elasticities of supply and demand, and of the sizes of the upward shifts in the supply curve. The elasticities have been calculated in this study, since existing estimates were not available. Linear supply and demand functions or ones having constant elasticity are assumed. Estimated price elasticities of supply are based on U.S. avocado production data for the years 1960/61-1990/91 (Appendix 3).[17] Results of the regressions are given below.

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[16] Pinstrup-Andersen, Ruiz de Londoño, and Hoover (1976) use a similar procedure to derive the new equilibrium price and quantity resulting from a rightward shift of the supply curve.

[17] Production levels for 1960/61 to 1969/70 are taken from Takele (1988); for subsequent years, from USDA (1991).

$$Q^S = -86{,}615 + 98.91*P(-1) + 1.00*Q^S(-1) \quad (8)$$
$$\quad\;\; (-2.20) \quad\; (3.40) \qquad\qquad (7.72)$$

$$\ln Q^S = -3.58 + 0.58*\ln P(-1) + 0.97*\ln Q^S(-1) \quad (9)$$
$$\quad\;\; (-1.5) \quad (3.13) \qquad\qquad (7.01)$$

$$Q^S = 40.13*P(-1) + 0.77*Q^S(-1) \quad (10)$$
$$\quad\;\; (3.31) \qquad\quad (9.65)$$

$$\ln Q^S = 0.34*\ln P(-1) + 0.81*\ln Q^S(-1) \quad (11)$$
$$\quad\;\; (3.67) \qquad\quad (15.06)$$

In the above equations, Q^S represents total avocado production measured in tons, while P is the price of avocado (dollars per ton) deflated by the implicit GNP deflator. The t-ratios are indicated in parentheses.

Price elasticities of supply for equations 9 and 11 are given directly by the price coefficients: 0.58 and 0.34, respectively. The supply elasticities for equations 8 and 10 are 0.71 and 0.29. They are obtained using the elasticity of supply formula $(\delta Q^S/\delta P)(P/Q^S)$, where P and Q^S are average price and quantity. The arithmetic mean (0.48) of these four elasticity measures is used for the base analysis.

The price elasticity of demand is estimated similarly using data for 1975-1990 (Appendix 4).[18] The estimated equations are as follows:

$$Q^D = 242{,}277 - 52.2*P \quad (12)$$
$$\quad\;\; (4.74) \quad (-1.53)$$

$$\ln Q^D = -15.96 - 0.55*\ln P \quad (13)$$
$$\quad\;\; (7.11) \quad (-1.78)$$

$$\ln Q^D = -0.61*\ln P + 1.79*\ln Y - 0.5*RHO \quad (14)$$
$$\quad\;\; (-3.52) \qquad (13.01) \qquad (1.98)$$

Q^D is the quantity of avocado demanded (net of exports and imports), P is unit price per ton deflated by the consumer price index, Y is per capita disposable personal income measured in constant dollars (1982=100), and RHO is the Cochrane-Orcutt correction for first-order autocorrelation. The price elasticity of demand for equation 12 is -0.45, obtained using the elasticity of demand formula $(\delta Q^D/\delta P)(P/Q^D)$, where P and Q^D are average price and

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[18]Consumption levels for 1975 to 1987 are taken from Brown and Suarez (1991); levels for subsequent years are computed using production and trade data taken from USDA (1992).

quantity. The other elasticities are directly read from the price coefficients: -0.55 and -0.61. The arithmetic mean of these demand elasticities, -0.54, is used for the base analysis.

Estimated Results

As discussed, the cost of applying additional pesticides in response to the weevil infestation and related pest outbreaks would increase average yearly production costs per acre by $2,321.75 (indicated as r_1 in Figure 3), and the corresponding value for k_1, the proportional increase in costs, is 41 percent. Yield is assumed to decrease by 20 percent due to the infestation and the related outbreaks, which would shift the supply curve to the left. The yield reduction can be interpreted as an upward shift of the supply curve (r_2 in Figure 3), and the corresponding k_2 value is 31 percent.

Estimated welfare losses of a weevil infestation in California, based on these supply shifts and using equations 6 and 7, are shown below. For this estimation, the initial equilibrium quantity and price (P_1 and Q_1) are set at the U.S. averages for the period from 1980/81 to 1990/91: 215,000 tons and $815 per ton. First-stage elasticities are $\varepsilon = 0.48$ and $\eta = 0.54$, and second-stage elasticities are $\varepsilon = 0.64$ and $\eta = 0.72$.

	Million Dollars
Annual losses of consumer surplus	58.2
Annual losses of producer surplus	65.4
Annual total losses	123.6

Sensitivity of the Results

It is important to recognize that the values of three parameters are critical in the estimation of relative economic impacts: the percentage increase in production costs due to the pesticide applications (k_1); the yield reduction, interpreted as an upward shift of the supply curve (k_2); and the price elasticities of supply (ε) and demand (η). The distribution of social losses between producers and consumers is determined by the relative magnitudes of the price elasticities. If the demand for avocado were perfectly elastic, all the losses due to infestation and increased production costs would be borne by the producers. At the other extreme, if the demand for avocado were perfectly inelastic, all additional costs would be shifted to consumers.

The price elasticities derived from the estimated supply and demand functions described above are relatively inelastic (indicating that producers and consumers respond to price changes at a rate less than the percentage change in price). The effects on producer and consumer losses of assuming price elasticities greater or less than $\varepsilon = 0.48$ and $\eta = 0.54$ are shown in Appendixes 5 and 6. In summary, most of the cost is borne by consumers when

$(\varepsilon/\eta) > 1$, while producers bear the major share of the losses when $(\varepsilon/\eta) < 1$. Consumers and producers share the cost equally when this ratio equals 1.

Table 2 illustrates the impact on social losses if the proportional increase in cost of avocado production, k_1, is set at levels above or below 0.41, that is, if increased pesticide costs due to the infestation were different than is assumed in the base analysis. Varying k_1 results in new k_2 values as well, even though the assumed reduction in yield is held at 20 percent, since the intermediate supply curve, S_2, changes. Values selected for k_1 are 0.20, 0.30, 0.41, 0.50, and 0.60. In each case, initial elasticities are $\varepsilon = 0.48$ and $\eta = 0.54$, $Q_1 = 215{,}000$ tons, and $P_1 = \$815$ per ton.

Table 2

Welfare Effects of an Increase in Avocado Production Costs Due to Infestation, for Various Levels of Cost Increase[1]

k_1	0.20	0.30	0.41	0.50	0.60
k_2	0.36	0.34	0.31	0.29	0.28
P_1 ($)	815	815	815	815	815
Q_1 (tons)	215,000	215,000	215,000	215,000	215,000
P_3 ($)	1,043	1,078	1,115	1,146	1,181
Q_3 (tons)	182,500	177,600	172,200	167,800	162,900
CL ($1,000)	(45,391)	(51,564)	(58,161)	(63,408)	(69,079)
PL ($1,000)	(51,071)	(58,016)	(65,437)	(71,339)	(77,718)
TL ($1,000)	(96,462)	(109,580)	(123,598)	(134,747)	(146,797)
CL/TL	0.47	0.47	0.47	0.47	0.47
PL/TL	0.53	0.53	0.53	0.53	0.53

[1]Terms are defined in the text; yield reduction of 20 percent is assumed.

As Table 2 shows, the greater the percentage increase in production costs (k_1), the higher the new equilibrium price and the smaller the new equilibrium quantity. For $k_1 = 0.41$ (the shift of the supply curve assumed in the base scenario), the price of avocados would increase by 37 percent and quantity produced would decrease by 20 percent.

The rows indicating consumer surplus losses (CL), producer surplus losses (PL), and total losses (TL) present the welfare effects corresponding to various values of k_1. Not surprisingly, welfare losses are directly related to the size of the increase in production costs, from \$96.5 million when $k_1 = 0.20$ to \$146.8 million when $k_1 = 0.60$. (The total value of U.S. avocado production in 1990/91 was about \$189 million.) As shown in the last two

rows of the table, 47 percent of the loss would be borne by consumers and 53 percent by producers. The distribution of losses is not affected by varying the value of k_1.

Similar impacts on producer and consumer surplus can be observed when k_1 is held constant, while k_2, the percentage shift corresponding to the yield reduction, is varied. In Table 3, yield reductions of 10, 15, 20, 25, and 30 percent are assumed, and corresponding k_2 values are computed. As in Table 2, initial elasticities are $\varepsilon = 0.48$ and $\eta = 0.54$, $Q_1 = 215{,}000$ tons, and $P_1 = \$815$ per ton.

Table 3

Welfare Effects of a Reduction in Avocado Yield Due to Infestation, for Various Levels of Reduction[1]

Yield Loss (%)	10	15	20	25	30
k_1	0.41	0.41	0.41	0.41	0.41
k_2	0.16	0.23	0.31	0.39	0.47
P_1 ($)	815	815	815	815	815
Q_1 (tons)	215,000	215,000	215,000	215,000	215,000
P_3 ($)	1,044	1,080	1,115	1,151	1,187
Q_3 (tons)	182,400	177,300	172,200	167,100	162,000
CL ($1,000)	(45,469)	(51,906)	(58,161)	(64,234)	(70,124)
PL ($1,000)	(51,155)	(58,399)	(65,437)	(72,269)	(78,897)
TL ($1,000)	(96,624)	(110,305)	(123,598)	(136,503)	(149,021)
CL/TL	0.47	0.47	0.47	0.47	0.47
PL/TL	0.53	0.53	0.53	0.53	0.53

[1]Terms are defined in the text; increase in production costs of 41 percent is assumed.

Results shown in Tables 2 and 3 are instructive in considering the sensitivity of the estimated welfare losses to assumptions regarding the increase in production costs and the reduction in yield. Table 2 indicates that an increase in production costs of 20 percent and a 20 percent reduction in yield would lead to annual losses of around $100 million; if the increase in costs were three times as great (60 percent of original costs), annual losses would be about $150 million. In Table 3, if production costs were to increase by 41 percent and yields fell by 10 percent, annual losses would total around $100 million; yield reductions of 30 percent would lead to annual losses of about $150 million.

In summary, U.S. avocado producers and consumers would suffer welfare losses from an exotic weevil infestation in California totalling nearly $123.6 million per year. While a number of assumptions underlie this estimation, the analyses shown in Tables 2 and 3

indicate that annual losses would be considerable over a range of costs increases and yield declines.

Appendix 1

Exotic Pests of Concern

The analysis performed in this study is of a hypothetical infestation of California's avocado groves by an exotic pest, such as *Conotrachelus aguacatae* or *Copturus aguacatae*. The stem and seed weevils and seed moth represented are described here.

Conotrachelus perseae and *C. aguacatae* (avocado seed weevils)

Distribution. These seed weevils occur in Mexico and in Central America as far south as Panama (Whitehead 1979, Ebeling 1959). In Mexico, *C. perseae* is reported for the States of Michoacan, Puebla, Veracruz, and Jalisco; *C. aguacatae* is reported for the States of Coahuila, Jalisco, Michoacan, Nayarit, Queretaro, Guanajuato, Puebla, and Morelos (Whitehead 1979, Sanidad Vegetal 1992).

Host. The avocado (*Persea americana*) is the only host reported for *C. perseae* and *C. aguacatae*. Interception of *Conotrachelus* spp. by PPQ officials indicates that the Mexican race of avocado is heavily attacked (USDA 1941). Sanidad Vegetal (1992) reports that the "creole type of avocados" (Mexican race) are preferred but the Hass variety is attacked by both of these weevils. Since *Conotrachelus* spp. are reported as a pest of avocado in Central America, it should be assumed that various varieties of the Guatemalan race can be attacked.

Biology. Eggs are deposited on young, undeveloped fruit and the larvae feed in the seed until they are fully developed. When fully developed the larvae exit the fruit and pupate in the soil. Sanidad Vegetal (1992) reports that from one to four larvae of *C. perseae* develop in each infested fruit. Sleeper (1979) reports that up to 28 larvae can be found in one fruit. Generally, damaged fruit falls to the ground before the fruit is fully developed (Sanidad Vegetal 1992, Sleeper 1979). Plant Protection and Quarantine officials have found larvae in various stages of development in intercepted avocado being smuggled into the United States, indicating that infested fruit does develop to a marketable stage (USDA 1941). The adults are active at night and feed to at least some degree on the fruits, leaves, and stems of avocado trees. In Mexico, *C. perseae* is reported to have two generations a year.

Economic Importance. Ebeling (1959) ranked both of these weevils as minor pests of avocados. Sanidad Vegetal (1992) reported that on neglected farms the infestation rate could be between 7 and 18 percent of the fruit and as high as 66 percent from creole trees. Field controls reported by Sanidad Vegetal

(1992) include foliage and ground application of pesticides, raking of the ground to expose the pupae, and the collection and destruction of fallen fruit.

Copturus aguacatae (an avocado stem weevil)

Distribution. This weevil is known only in Mexico and is reported to occur in the States of Guerrero, Puebla, Morelos, and Michoacan (Whitehead 1979, Kissinger 1957).

Host. The avocado (*Persea americana*) is the only reported host (Kissinger 1957, Muniz 1959). Adult weevils reared from larvae found in smuggled avocado fruit intercepted on the Mexican border have been identified as *C. aguacatae*. In recent years, hundreds of identical larvae have been found in smuggled Hass avocados intercepted by Plant Protection and Quarantine officials, mainly at El Paso, Texas.

Biology. The weevil bores into small new stems and branches, and can affect older branches when populations are large. A maximum of eight eggs are laid in the epidermis of the plant. Oviposition occurs for the most part in April and May by a first generation and in October and November by a second generation. Adults emerge from May to early July and from November to February (Muniz 1959).

Economic Importance. This species and related weevils have been reported to cause great destruction to avocado trees. Boring by this pest causes die-back of the branches, with uncontrolled infestations resulting in reduced tree size. Ebeling (1959), Sleeper (1978), and Whitehead (1979) consider *C. aguacatae* to be a major pest of avocado. Additional damage may be caused by secondary infestations by bacteria, fungi, and viruses (Muniz 1959). This pest and related ones can be controlled with repeated foliage spraying of contact pesticides.

Heilipus lauri (an avocado seed weevil)

Distribution. This pest occurs in Mexico and at least as far south as Colombia. In Mexico, it has been reported in the States of Hidalgo, Mexico, Morelos, Veracruz, Guerredo, Puebla, and Tlaxcala (Garcia 1962, Sanidad Vegetal 1992).

Host. Sanidad Vegetal (1992) reports that this weevil prefers creole avocados (Mexican race), but also attacks improved avocado varieties.

Biology. Ebeling (1959) reports that there is one generation per year. The winter is spent in the adult stage and eggs are deposited in the developing fruit

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in May, June, and July. The larva tunnels to the seed where it feeds and pupates. After the adult leaves the fruit, it feeds on the leaf, bud, sprout, and fruit of the avocado. Sometimes pupation takes place in the soil from fallen fruit. In a study of the pest conducted in the State of Morelos, an average of two larvae were found per infested seed and two generations were propagated in a 15½ month period (Sanidad Vegetal 1992).

Economic Importance. Ebeling (1959) ranked *H. lauri* as a major pest of avocado. In certain areas of Mexico it has caused up to 80 percent fruit loss (Garcia 1962). Sanidad Vegetal (1992) reports various field controls including foliage application of pesticides directed at the adults, weed control, and destruction of fallen fruit.

Stenoma catenifer (an avocado seed moth)

Distribution. This pest occurs from Mexico south to Brazil. In Mexico it has been found in the States of Veracruz, Tamaulipas, Oaxaca, Chiapas, Nuevo Leon, Guerrero, and Colima (Acevedo 1973).

Host. This moth is reported to attack *Persea americana* (avocado), *Persea schiedeana* ("chinini") and *Beilschmedia* spp. ("anayo") (Acevedo 1973, USDA 1980).

Biology. The winter is spent as an adult in the soil or leaf litter. In the spring the female mates and deposits eggs on the stem and fruit of its hosts. The larva bores into the stems and fruit, and feeds on the seed within the fruit. Pupation takes place in or on the soil. The number of generations per year varies depending on the availability of fruit (Acevedo 1973, Ebeling 1959, and USDA 1980).

Economic Importance. This is a major pest of avocado (Ebeling 1959). The larvae damage the terminal twigs and can often kill young trees. The damage to stems can also result in fruit drop, and damaged fruit is rendered unmarketable. It limits avocado production in tropical areas of Mexico, and in Venezuela is considered a major avocado pest (Boscar and Godoy 1982). Fruit infestation rates as high as 94 percent have been reported. As many as 14 treatments of pesticide per season are required to eliminate damage by this pest (Acevedo 1973).

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Appendix 2

Consumer and Producer Surplus

Economic impacts for the United States of a weevil infestation of California's avocado groves are approached in terms of welfare losses that would be borne by consumers and producers. Estimation of the magnitude of these losses is based on the concept of consumer and producer surplus.

Consumer surplus is the additional value that consumers receive for a commodity beyond what they pay for it, that is, the maximum sum of money a consumer would be willing to pay for a given amount of the item, less the amount he actually pays (Mishan 1976). For consumers in the aggregate, it can be depicted on a graph as the area between the demand curve and the market price (the shaded area in Figure A).

Producer surplus is the analogous measure for producers, representing the difference between the market price the producer receives and the marginal cost of producing each unit of the commodity (Pindyck and Rubinfeld 1989). Producers enjoy a benefit—a surplus—from selling units that are produced at a cost that is less than the market price. This surplus is the profit on the unit, plus any rents accruing to factors of production. Rent can be thought of as a payment in excess of that necessary to maintain a factor in its current occupation. For the market as a whole, producer surplus can be portrayed as the area above the supply curve up to the market price (the shaded area in Figure B).

A shift in either the supply or demand for a commodity results in a new price-quantity equilibrium, and changes the amount of surplus enjoyed by consumers and producers. The assumed weevil infestation would cause upward shifts in the supply of avocado, as shown in Figure 3 of Section 4, with consequent welfare losses for consumers and producers.

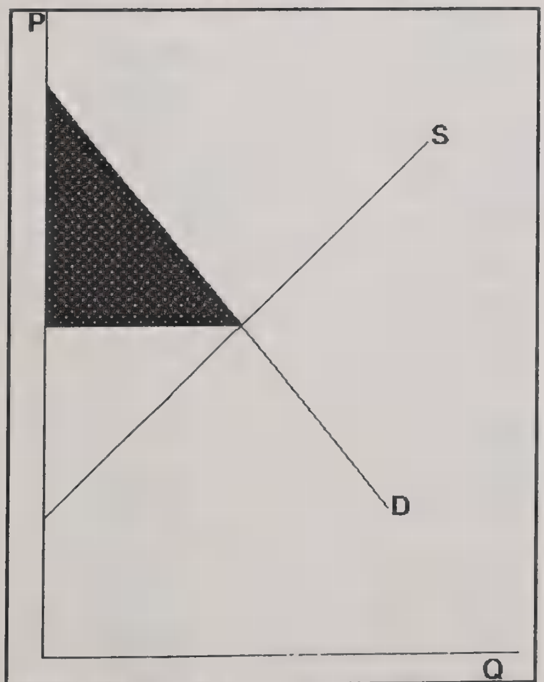

Figure A. Consumer Surplus

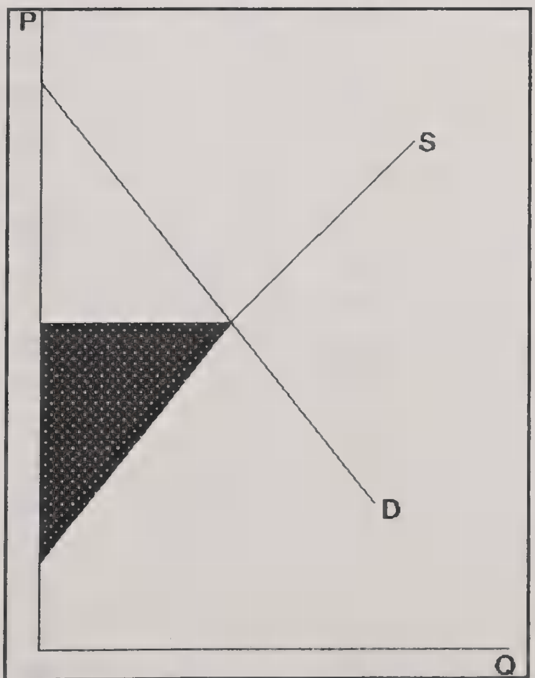

Figure B. Producer Surplus

[illegible]

Consumer and Producer Surplus

[illegible] for the United States as a [illegible] measured in terms of welfare [illegible] of the [illegible] occur [illegible].

[illegible] of the [illegible] of the [illegible] price [illegible] (see Figure A).

[illegible] marginal cost of production [illegible] of the [illegible] a whole, producer surplus [illegible] (Figure B).

[illegible] supply or demand for a commodity [illegible] would cause upward [illegible] consumers and producers.

Appendix 3

Data Used in the Estimation of the Price Elasticity of Supply for Avocado

The following data for the years 1960/61 to 1990/91 were used to estimate the supply equations 9, 10, 11, and 12 in Section 4.

Year	U.S. Production (tons)	Producer Price ($ per ton)	GNP Implicit Deflator (1982 = 100)
1960/61	40,350	284	30.9
1961/62	56,200	209	31.2
1962/63	51,700	239	31.9
1963/64	60,700	231	32.4
1964/65	36,750	402	32.9
1965/66	61,250	271	33.8
1966/67	80,900	204	35.0
1967/68	52,500	383	35.7
1968/69	73,950	289	37.7
1969/70	46,450	561	39.8
1970/71	85,800	357	42.0
1971/72	45,400	691	44.4
1972/73	89,300	499	46.5
1973/74	73,700	672	49.5
1974/75	127,400	450	54.0
1975/76	87,400	826	59.3
1976/77	141,100	566	63.1
1977/78	117,700	735	67.3
1978/79	146,100	645	72.2
1979/80	102,300	1,256	78.6
1980/81	268,800	377	85.7
1981/82	182,800	662	94.0
1982/83	236,700	463	100.0
1983/84	274,000	379	103.9
1984/85	229,500	557	107.9
1985/86	188,500	953	111.5
1986/87	302,700	344	114.2
1987/88	209,000	1,030	117.7
1988/89	192,600	1,140	121.6
1989/90	139,050	1,800	126.6
1990/91	145,050	1,300	131.4

Appendix 4

Data Used in the Estimation of the Price Elasticity of Demand for Avocado

The following data for the years 1975 to 1990 were used to estimate the demand equations 13, 14, and 15 in Section 4.

Year	Consumption (tons)	New York Wholesale Price ($ per pound)	Per Capita Disposable Income ($)	Consumer Price Index
1975	74,447	0.45	8,944	59.8
1976	124,437	0.70	9,175	61.6
1977	103,961	0.58	9,381	65.5
1978	129,257	0.65	9,735	72.0
1979	86,018	0.70	9,829	79.9
1980	235,788	0.94	9,722	86.8
1981	148,017	0.54	9,769	93.6
1982	207,989	0.65	9,725	97.4
1983	241,695	0.54	9,930	99.4
1984	198,628	0.50	10,419	103.2
1985	167,261	0.55	10,625	105.6
1986	276,100	0.66	10,905	109.0
1987	205,134	0.46	10,946	113.5
1988	198,363	0.84	11,368	118.2
1989	140,938	0.75	11,531	125.1
1990	136,599	1.11	11,508	132.4

Appendix 5

Effects of Increased Avocado Production Costs and Decreased Yield, Assuming Various Elasticities of Supply

Analytical results shown in the box below demonstrate the effect on estimated social losses from an avocado weevil infestation of assuming different price elasticities of supply. The information is presented in the same format as Tables 2 and 3 of Section 4. The percentage increase in production costs (k_1 = 0.41), the assumed yield reduction (k_2 = 0.20), the price elasticity of demand (η = 0.54), the initial equilibrium price (P_1 = $815 per ton), and the initial equilibrium quantity (Q_1 = 215,000 tons), are held at their estimated values. The elasticity of supply, ε, is assigned values of 0.10, 0.25, 0.48 (the elasticity assumed in the base scenario), 0.75, and 1.00. As can be seen, the greater the supply elasticity, the higher the new equilibrium price, P_3, and the smaller the new equilibrium quantity, Q_3.

Total welfare losses, TL, range from $135 million when ε = 0.10, to $117 million when ε = 1.00. Changes in the incidence of the losses are significant, as shown in the last two rows of the table. Consumers bear 31 percent (producers, 69 percent) of losses when ε = 0.10, compared to 57 percent (producers, 43 percent) when ε = 1.00. The increase in production costs and the reduction in yield, represented by k_1 and k_2, principally determine the total social losses that would result from infestation, but the distribution of losses between consumers and producers depends upon the price elasticities of supply and demand.

ε	0.10	0.25	0.48	0.75	1.00
k_1	0.41	0.41	0.41	0.41	0.41
k_2	0.39	0.34	0.31	0.29	0.28
P_1 ($)	815	815	815	815	815
Q_1 (tons)	215,000	215,000	215,000	215,000	215,000
P_3 ($)	1,022	1,069	1,115	1,149	1,169
Q_3 (tons)	185,600	178,800	172,200	167,500	164,600
CL ($1,000)	(41,361)	(50,081)	(58,161)	(63,784)	(67,155)
PL ($1,000)	(93,695)	(79,052)	(65,437)	(55,935)	(50,226)
TL ($1,000)	(135,056)	(129,133)	(123,598)	(119,719)	(117,381)
CL/TL	0.31	0.39	0.47	0.53	0.57
PL/TL	0.69	0.61	0.53	0.47	0.43

Appendix 6

Effects of Increased Avocado Production Costs and Decreased Yield, Assuming Various Elasticities of Demand

Analytical results shown in the box below demonstrate the effect on estimated social losses from an avocado weevil infestation of assuming different price elasticities of demand. The information is presented in the same format as Tables 2 and 3 of Section 4. The percentage increase in production costs (k_1 = 0.41), the assumed yield reduction (k_2 = 0.20), the price elasticity of supply (ε = 0.48), the initial equilibrium price (P_1 = \$815 per ton), and the initial equilibrium quantity (Q_1 = 215,000 tons), are held at their estimated values. The elasticity of demand, η, is assigned values of 0.10, 0.25, 0.54 (the elasticity assumed in the base scenario), 0.75, and 1.00. As can be seen, the greater the demand elasticity, the lower the new equilibrium price (although P_3 is always greater than P_1), and the smaller the new equilibrium quantity, Q_3.

Total welfare losses, TL, range from \$135 million when η = 0.10, to \$119 million when η = 1.00. Changes in the incidence of the losses are significant, as shown in the last two rows of the table. Consumers bear 66 percent (producers, 34 percent) of losses when η = 0.10, compared to 39 percent (producers, 61 percent) when η = 1.00. The increase in production costs and the reduction in yield, represented by k_1 and k_2, principally determine the total social losses that would result from infestation, but the distribution of losses between consumers and producers depends upon the price elasticities of supply and demand.

η	0.10	0.25	0.54	0.75	1.00
k_1	0.41	0.41	0.41	0.41	0.41
k_2	0.30	0.31	0.31	0.32	0.32
P_1 (\$)	815	815	815	815	815
Q_1 (tons)	215,000	215,000	215,000	215,000	215,000
P_3 (\$)	1,246	1,184	1,115	1,086	1,062
Q_3 (tons)	185,700	179,200	172,200	169,200	166,700
CL (\$1,000)	(88,818)	(73,950)	(58,161)	(51,554)	(46,214)
PL (\$1,000)	(46,350)	(55,622)	(65,437)	(69,534)	(72,841)
TL (\$1,000)	(135,168)	(129,572)	(123,598)	(121,088)	(119,055)
CL/TL	0.66	0.57	0.47	0.43	0.39
PL/TL	0.34	0.43	0.53	0.57	0.61

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